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Greening cities to ensure biosphere functional integrity: Insights from Rotterdam and Lagos

Joyeeta Gupta [a,g,*], Agni Kalfagianni [b], Chukwumerije Okereke [d,g], Fran Meissner [e], Abhigyan Singh [f], Carissa Champlin [f,e], Alyssa Delarosa [e], Sofi Joaquín Fernández [f], Miguel Avides [b], Zoé Sarolta Héjja [a], Chukwueloka Okeke [c,d], Elin Wahlqvist [f], Paola Fezzigna [a]

[a] University of Amsterdam, Amsterdam, the Netherlands
[b] Erasmus School of Social and Behavioural Sciences, Rotterdam, the Netherlands
[c] Department of Earth Sciences, Anchor University Lagos, Nigeria
[d] School of Policy Studies, University of Bristol, UK
[e] University of Twente, Enschede, the Netherlands
[f] Department of Human-Centered Design, Delft University of Technology, Delft, the Netherlands
[g] IHE-Delft Institute for Water Education, the Netherlands

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ABSTRACT

The Earth Commission has proposed that 20-25% of every square kilometre of managed lands, including in cities, be reserved for nature to ensure its local functioning and human wellbeing -biosphere functional integrity boundary (BFI). This research adopted a multi-method justice-oriented approach grounded in the Earth System Justice framework to assess the challenges and opportunities of implementing this proposed biosphere functional integrity boundary in Rotterdam and Lagos. We conclude: (a) This proposed scientific *boundary* precedes global policy but complements the EU's voluntary urban greening guidelines. (b) Good quality green is inequitably distributed in case study countries for different reasons. (c) Combining existing large-scale planning and subsidizing small-scale greening efforts should enable Rotterdam to achieve the boundary, despite risks of gentrification, inequitable access, and poor-quality green. For Lagos, development imperatives compete with existing greening. (d) This research has enhanced Earth system justice and its 9 criteria for just boundaries. We believe that adopting a contextually relevant BFI boundary may enable equitable distribution of good quality and accessible green especially for the people who need it most.

1. Introduction

This paper presents the results of the FRAME project examining the challenges of implementing the proposed biosphere functional integrity (BFI) boundary in cities (Gupta et al., 2024a, 2024b) in the context of biodiversity governance and Earth System Justice. Biodiversity loss severely impacts species, ecosystems and nature's contribution to people (NCP) (UNEP, 2019) which refers to how nature flourishes and enables human wellbeing (Pascual et al., 2017). Globally, species loss is at 69% since 1970 (WWF, 2022) and we may be in the midst of the 6th biodiversity extinction event (Novacek, 2007).

To address this problem, the planetary boundaries community has proposed boundaries beyond which systems become unstable or pass tipping points with irreversible impacts. Within this community, the Earth Commission,[1] has proposed a safe and just BFI Boundary: 20–25% of every square kilometre of managed or human-modified lands (urban and rural areas) should have a diverse semi-natural habitat incorporating native species (Rockström et al., 2023; see 2.1). Such a 'just' boundary draws on the Earth Commission's framing of 'Earth System Justice' (Gupta et al., 2024a, 2024b; see 2.2).

Given limited scholarship on this BFI boundary proposal, we ask: What are the challenges and potential of adopting and implementing a safe and just biosphere integrity (BFI) boundary using Earth System Justice (ESJ) in urban policies in different political, economic and social

* Corresponding author. University of Amsterdam, Amsterdam, the Netherlands.
E-mail address: j.gupta@uva.nl (J. Gupta).

[1] The Earth Commission was set up by Future Earth to conduct interdisciplinary scientific work specifically on boundaries for the Earth's processes and transformation processes.

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contexts? We use the theoretical framework of Earth System Justice (ESJ) and urban greening and justice scholarship (see 2.2) and conduct case studies in Rotterdam and Lagos (see 2.1). These cities offer empirical insights on the feasibility and justice implications of implementing the BFI boundary across different urban settings.

Section 2 presents the theory, Section 3 the methodology and Section 4 discusses the challenges and potential of adopting a BFI in our case studies. Section 5 analyses the results from an Earth System Justice perspective and Section 6 concludes.

2. Theory: biosphere functional integrity, Earth System Justice, just urban greening

2.1. Earth system boundary: biosphere functional integrity (BFI)

Given growing Earth System degradation, the Earth Commission proposed eight safe (prevents irreversible harm to planetary processes) and just (prevents significant harm to humans) (see 2.2) Earth System Boundaries for climate, the biosphere, fresh water, nutrients, and air pollution at global and sub-global scales. These processes span the major components of the Earth's life-support systems (Rockström et al., 2023). Two boundaries focus on the biosphere: (a) 50-60% of land should be left as intact nature (supporting the Indigenous people and local communities who live there); and (b) 20-25% of every square kilometre of managed lands should be reserved for diverse nature (BFI boundary). To derive this latter boundary, this paper's focus, the Earth Commission analyzed six essential Nature-Based Contribution Points at the local level to assess the minimum characteristics (area, quality, spatial configuration) necessary to prevent the loss of benefits or harm to human health and well-being. These encompass pollination, pest and disease management, regulation of water quality, soil preservation, mitigation of natural hazards, and recreational opportunities. While this boundary is proposed globally, it must be applied locally as many biological groups have limited mobility, implying that the spatial configuration of their habitat drives the provision of NCP. Moreover, local boundaries can differ, ranging from 10 to 15% in certain landscapes (e.g. riparian ecosystems, agricultural areas with high crop diversity) to 50% in others (e.g. sloping terrains or regions prone to erosion or frequent natural hazards) (Gupta et al., 2024a, 2024b). Therefore, context specificity is key in applying these BFI boundaries.

These boundaries are critical to biodiversity governance and are needed to address the drivers of biodiversity loss (e.g. climate change; land use change; development), to protect nature, and promote its services to humans (IPCC, 2018). These services contribute material goods (e.g. fruit and vegetables), services (e.g. flood protection), and mental and physical health benefits (Brondízio et al., 2019). Human wellbeing is harmed by deteriorating NCPs (Mohamed et al., 2024). Reserving land for nature, including nature-based solutions, can help provide flood protection and cooling, and regulate air and water quality while helping to mitigate or adapt to climate change and preserve or enrich biodiversity in rural and urban areas (Convention on Biological Diversity, 2022; Lavorel et al., 2020). However, without attention to justice, urban greening can exacerbate displacement, dispossession and marginalization of groups and thereby undermine the challenge it was intended to solve.

2.2. Earth System Justice and just urban greening scholarship

Hence, we examine the justice implications of the proposed boundaries using the Earth System Justice framework (ESJ) that underlies the work of the Earth Commission, and urban green scholarship.

2.2.1. Earth System Justice conceptualized

The ESJ framework evolved from a paper discussing why social scientists needed to engage with planetary boundaries (Gupta et al., 2023). It drew on an extensive literature review of environmental/water/ecological/climate justice from local to global level and Earth Commission debates and workshops. It aimed to ensure that planetary boundary science accounts for relevant justice issues. ESJ builds on calls for a just approach to addressing ecological challenges in international scientific assessments (Gupta, Prodani et al., 2024). It bridges local to global justice scholarship and is anchored in transformative rather than conservative justice approaches (Gupta et al., 2023). It also links planetary boundaries to basic needs (Rammelt et al., 2023; see 2.2.2) in the face of intensifying climate extremes (Fezzigna et al., 2025) (see Fig. 1).

NB. *This figure visualizes the conceptualization and operationalization of Earth System Justice. Conceptualization (upper half of sphere) includes ideal/transformative, recognition, and epistemic justice; the 3I's of justice; procedural; and substantive justice. Operationalization (bottom half) is undertaken through ends and means: Ends refers to safe and just boundaries building on not causing harm to others using the 3I's; and foundations reserving space within the boundaries for meeting the minimum needs of all. Means refer to (a) addressing the drivers of the 'problem' and inequality; (b) allocating liability for harm caused; (c) reallocating the remaining space within the boundaries; and (d) reallocating responsibilities between actors. The arrows show how the conceptualization influences operationalization.*

ESJ argues that justice, in the context of Earth System problems, needs to be ideal (aiming at normative fairness)(Kalfagianni and Meisch, 2020) and transformative (not procedurally conservative). It includes recognition justice (prioritizing the perspective of the marginalized) (Kashwan et al., 2020) and epistemic justice (building also on non-western knowledges of e.g. indigenous peoples, local communities (Johnson and Sigona, 2022). This implies adopting the 3I's - Interspecies justice and Earth system stability (I1), Intergenerational justice (between past, present and future) (I2) and Intragenerational justice (between countries, communities and individuals) (I3).

ESJ promotes procedural justice (access to: information, decision-making, civic space and judicial remedy). Since equal procedural access may not adequately support the most marginalized, extra effort is necessary to ensure that marginalized people can constructively participate. ESJ also includes substantive justice: addressing the drivers of environmental degradation and vulnerability; and (re-)allocating the remaining resources; risks; and related responsibilities; building on the access and allocation framework developed by the Earth System

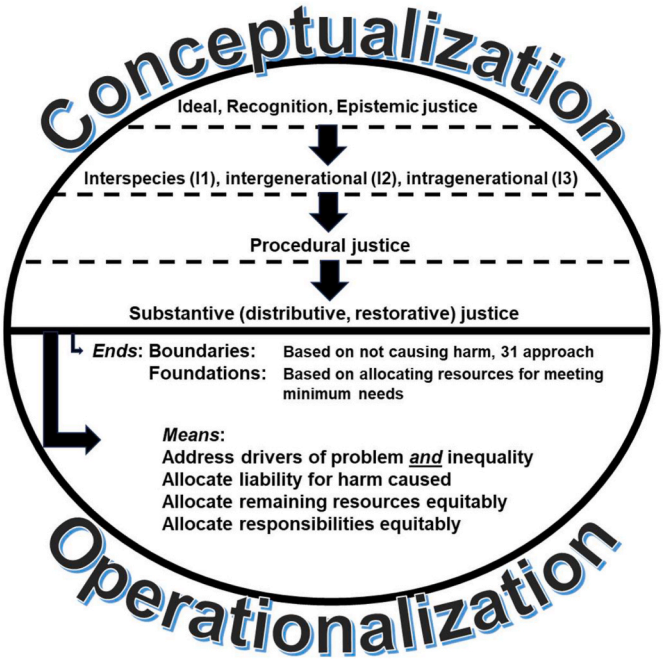


Fig. 1. Earth System Justice framework.

Governance community (Gupta and Lebel, 2020).

2.2.2. Earth System Justice operationalized: just boundaries

The operationalization of ESJ is achieved by identifying *ends*: (a) quantifying just boundaries from the local to global level for different processes (e.g. climate, biosphere) by balancing the 3I's aiming to minimize significant harm to others and nature (the focus of this paper) (Rockström et al., 2023). This determines the useable ecospace; (b) quantifying the ecospace needed to meet the minimum needs of people using the same units as the boundaries. In terms of *means*, since we have crossed seven out of eight safe and just boundaries without meeting minimum needs, we need to return to the safe and just ecospace but also ensure that enough ecopace is left for meeting minimum needs. This involves addressing the driving factors of environmental degradation and inequality, technology development and reallocating remaining resources, risks and responsibilities.

2.2.3. Nine aspects relevant to just boundaries

Just Boundaries have 9 criteria/conditions (Gupta et al., 2023). (a) Quantitative boundaries must have a qualitative aspect: e.g. a global aerosol boundary should also account for local air quality. (b) Local contextual issues need to be accounted for in boundaries: e.g. a water boundary should account for local geography; (c) Abstract global boundaries need to be translated to local level: e.g. the 1 m^3 for an aerosol boundary or a 1 km^2 for BFI makes the boundary more relatable to people; (d) Boundaries need to be spatially analyzed as harm is unevenly distributed across the world. Hence Rockström et al. (2023) mapped how many boundaries have been crossed worldwide. (e) Such spatial analysis needs to be linked to spatial maps of poverty as a proxy for inequality/vulnerability to show who is exposed to such harm. Hence, Gupta et al. (2024a); (2024b) overlaid poverty maps with maps displaying where boundaries were crossed to show how these intersect. (f) Boundaries cannot reveal who is causing harm to whom and this requires complementary analysis. (g) Boundaries need to be achieved in a just manner. (h) Boundaries make a limited contribution to justice, and (i) need to be debated locally and adapted to be procedurally just.

2.2.4. Critique of ESJ and just boundaries

Before undertaking the research, FRAME partners organized an international online workshop with ten experts to assess whether ESJ was an appropriate concept to use (see 3.2). Experts found that the ESJ concept was useful for engaging seriously with earth system science and quantifying just boundaries; for expanding justice to non-humans – the 3I approach; for being multi-scalar; and for bridging with policymakers. However, participants argued that ESJ does not see nature as an equal moral subject (e.g. Celermajer et al., 2020); inadequately covers material timescales, global South views, and data justice, and argued that boundaries could be misused to obscure justice issues.

2.2.5. ESJ could learn from urban justice scholarship

Moreover, in relation to this paper, we argue that ESJ could benefit from urban justice and urban greening scholarship which is locally grounded. This literature discusses the benefits of urban greening through enhancing health, liveability, restoring ecosystems, increasing food production and decreasing the urban heat island effect. These benefits are achieved through contextually sensitive and locally implemented urban planning initiatives (Simon, 2016; Raddad, 2022). Local community gardens, for example, restore individual health and ecosystems (Ferris et al., 2001). The World Health Organization (2017) recognizes the physiological and psychological health benefits of urban green spaces especially for older residents and marginalized groups (Droomers et al., 2016).

Nevertheless, groups with lower socioeconomic status, often concentrated in crowded neighbourhoods, lack access to green space (Dzhambov et al., 2023). Such lack, caused by poor planning or high costs disproportionally impact marginalized groups (Mullenbach and Baker, 2020; Rigolon and Németh, 2018). The greening of poor neighbourhoods often leads to rising prices of land and housing making it unaffordable for poor people to remain in upgraded neighbourhoods (gentrification) (Wolch et al., 2014; Cole et al., 2017). This can be seen in how green space overlaps with gentrified areas in high-income countries (Anguelovski et al., 2022) and some cosmopolitan cities in the poorer countries (Sax et al., 2022).

Such gentrification impacting marginalized groups in global high income country contexts is often discussed in terms of race and socio-economic status. However, more research is needed on how urban greening impacts health, how green space is distributed amongst groups, and what is included under "green" in different global contexts (Tuhkanen et al., 2022).

2.3. Implications for this paper

The above discussion calls for integrating urban justice issues and the results of the international workshop into Earth System Justice and applying it in relation to the different contexts within which the BFI boundary (see 4) can be adopted and implemented (see 5.1). We also assess implications for the 9 criteria of boundaries (see 5.2). Based on the analysis we reflect on the feasibility of the 20-25% boundary and the potential differences in cities in high and middle income country settings.

3. Choice of cases and methodology

3.1. Choice of cases

No two cities can ever fully represent the historical, political and socio-cultural diversity that shapes cities and their greening efforts. Since cities differ, we do not aim at a traditional comparative analysis. The selection of Rotterdam (Netherlands) and Lagos (Nigeria) as case studies reflects both methodological intent and analytical significance in understanding the opportunities and challenges in implementing the BFI boundary in cities with different income levels. Rotterdam represents a city in a high income country with a strong planning tradition, institutional capacity and policy framework aligned with climate adaptation and urban greening. Conversely Lagos exemplifies a rapidly urbanizing megacity in a middle income country, where urban expansion, informality, and uneven development create complex challenges for urban greening, justice, and environmental governance. This deliberate choice enriches the analysis by highlighting the constraints, opportunities and justice implications of the BFI boundary across different socio-political, economic and ecological contexts. Furthermore, researchers' familiarity and existing collaboration in both cities provided access to local data, stakeholder networks and policy environment. Importantly, both cities have engaged in urban greening efforts. These cities can provide contrasting insights into how the BFI boundary might be justly implemented across urban settings globally.

3.2. Methodology

The research adopted a multi-method justice-oriented approach to assess the feasibility and implications of implementing the BFI boundary in cities in high and middle income countries. We first examined the Earth System Justice framework which underlies the BFI boundary to see if this framework was adequate. We thought it could be improved with lessons from more grounded urban greening and justice scholarship. To test out our theory we organized an international online workshop. We then refined the framework to account for data justice, consider context and quality, including timescales/diversity/connectivity of species/ecosystems as well as the risk of green gentrification (see also Obura et al., 2023; see 2.2).

In order to undertake our case studies, we reviewed the relevant global, European and African policy to assess how the BFI boundary is, if

at all, reflected in these policies and hence in the biodiversity policies of the case study cities (see 3). We then undertook the fieldwork in Rotterdam and Lagos, studying the local policies. We organized two face-to-face workshops in Rotterdam and Lagos attended by 12 and 20 experts (local officials, urban planners, academics, civil society actors and community leaders) respectively, recruited through the FRAME team's network and purposive sampling, and convened at external locations for 2-h sessions. The Nigerian workshop also built on a semi-structured interview focusing on identifying policy targets, factors affecting the distribution of urban green space, and factors to improve urban green space and justice issues. Data collection methods included audio recordings, photographs, note-taking, and participants' worksheets. Audio files were transcribed and anonymized, with participants informed of data collection procedures prior to the workshop. Exercises promoting both divergent and convergent thinking were integrated into each workshop, encouraging discussion, prioritization and consensus-building. Additionally, creative facilitation techniques such as energizing exercises and visual aids were utilized. Each session commenced with a general introduction of the proposed BFI boundary and followed a predefined agenda. The analysis focused on understanding how green spaces intersect with socioeconomic inequalities and urban development trajectories in Rotterdam and Lagos, focusing on interspecies, intergenerational, and intragenerational justice alongside procedural, distributive and epistemic justice, as well as the justice criteria with respect to boundaries. It should be noted that the BFI boundary is quite new, and the workshops revealed that experts were engaging with it constructively and providing insights into whether and how it could be implemented. The topics were not yet so mature that there were heated debates or major disagreements between the participants. This multi-pronged approach was meant to help us embed and better make sense of the relevance of the BFI target, what (justice) issues might arise in adopting and implementing such a target, and Under what conditions the BFI implementation would be just. The last step in the method was to integrate the results.

4. The policy context: global, European and African

4.1. The global policy context

The BFI is a contribution to global biodiversity governance. The 1992 Convention on Biological Diversity (CBD) and its 2022 Kunming-Montreal Global Biodiversity Framework (KM-GBF) builds on the findings of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES, 2019). Its targets include that at least 30% of land, inland waters, and marine areas, are conserved and managed via ecologically representative and well-connected systems while respecting indigenous and local community rights, integration into broader landscapes and seascapes, and that allow sustainable use compatible with conservation goals (Convention on Biological Diversity, 2022; Target 3). This is significantly lower than the intactness boundary of the Earth Commission.

Moreover, the KM-GBF binds governments to expand biodiversity-focused spatial planning procedures (CBD, 2022). Nations must coordinate biodiversity assessments and policies at global, national, and regional levels. In many nations, spatial planning choices are predominantly determined at the local and regional levels, which can create friction with perceived top-down national and global obligations (Carroll et al., 2022). Effectively linking evaluation procedures at global, national, and subnational levels might promote a "network of networks" of scientists and practitioners, bridging the gap between science and policy (Ruckelshaus et al., 2020). CBD requires national assessments to critically synthesize policy information (UNEP-WCMC, 2021). Recent publications by IPBES and CBD highlight that, in addition to reporting on biodiversity status and trends, monitoring direct and indirect causes of biodiversity loss must be included in assessments (CBD, 2022; IPBES, 2019). This global framework does not say anything about protecting BFI in managed lands including cities – the focus of this paper.

4.2. The European Union and Netherlands policy contexts

On a regional level, the EU Biodiversity Strategy, Nature Restoration Law, and General Union Environment Action Programme (EAP) jointly govern the quantity and quality of natural areas in the EU (European Commission, 2020; Council of the European Union, 2023; European Climate, Infrastructure and Environment Executive Agency, 2023; European Parliament and The Council of the European Union, 2022). These agreements set legally binding targets for restoring at least 30% of all EU's land and sea area by 2030 (European Climate, Infrastructure and Environment Executive Agency, 2023). The Environment Action Programme to 2030 (8th EAP) requires nations to develop their own nature restoration programmes in line with EU goals and targets. Specific to urban spaces, EU countries must preserve and increase their canopy cover by 5% by 2050 with the voluntary guideline of 3-30-300 calling for at least three trees to be visible from homes, at least 30% of a district's canopy to be covered by trees, and a maximum distance of 300 m to the closest public green space (European Parliament Council of the European Union, 2024).However, purely enforcing quantitative greening targets will not ensure high-quality results for climate, biodiversity and society (Bulkeley et al., 2023). This calls for investigating the BFI as both a quantitative and qualitative target.

The Netherlands has three critical policies and laws that govern green space and environmental issues. The Environment and Planning Act of the Netherlands consolidates and modernizes all environmental laws (Ministry of the Interior and Kingdom Relations, 2021). It aims to strike a balance between preserving and using the natural world. It develops Environmental Agendas to harmonize the visions of municipal to national government, however it does not have urban green space requirements and since it precedes the EU Nature Restoration Law, it does not refer to the EU 3-30-300 rule.

The Environmental Act includes the National Environmental Vision (NOVI), which is applicable under the Spatial Planning Act as a structural vision for 2050 (Ministry of the Interior and Kingdom Relations, 2021). Under the NOVI, the 2050 target calls for more greenery and space for nature again without specifying targets.

Lastly, the Dutch National Climate Agreement – "Klimaatakkoord" (Ministerie van Economische Zaken en Klimaat, 2019), aligns national goals with international climate commitments. It calls for nature-based solutions to reduce CO_2 emissions, including green spaces in urban and farm areas but it does not contain specific targets for land use plans in regard to nature in urban spaces.

In short, there is no concrete national policy concerning the provision of urban green spaces in the Netherlands, although it ambiguously acknowledges that green space should be encouraged for its social and environmental benefits, but leaves decisions to municipal governments (Heidrich et al., 2016).

4.3. The Rotterdam case

Rotterdam, with 650,000 residents on 325 km^2 of land (3043 residents per km^2) is the largest seaport in Europe (World Population Review, 2024). Following its destruction during WWII, it's urban planning accommodated the waves of immigration during the 1970s and 1980s (Nientied, 2018). Rotterdam South, where the case is located, is a working-class, culturally diverse area compared to the north of Rotterdam.

4.3.1. The local context and urban greening initiatives

Rotterdam is empowered to make decisions on green areas under Netherlands' laws (Heidrich et al., 2016). As a harbour city, its residents include many low-paid labourers. In the early 2000's, it adopted greening policies to attract higher-income residents and "international knowledge workers" (MIE, 2011, p.8). Some feared that this could exacerbate green gentrification (Pearsall, 2010), increase living costs, displace marginalized local populations, and produce inequalities in access to green spaces (Krings and Schusler, 2020; Pearsall, 2010; Rigolon and Németh, 2018; Stuiver et al., 2022).

In Rotterdam, socio-economic status determines who has access to urban green areas. A quantitative study (Kruize et al., 2007) concludes that lower income groups have reduced access to green spaces or access to poorer quality green spaces. Higher-income groups have better access to high-quality urban green areas. This is true across the Netherlands (de Vries et al., 2020). City policies ignore this, leaving urban green space allocation to the market, which favours higher-income residents (Kruize et al., 2007).

Nevertheless, urban green spaces in Rotterdam South have increased local living standards (Haas, 2017), demonstrating the positive impact green spaces can have on local communities. Recently, the Rotterdam municipality and public are calling for more inclusive climate policy, including equitable sharing of environmental goods and bads (Stuiver et al., 2022). Inclusive Climate Action Rotterdam, for example, is a municipal initiative advocating a "social approach to climate change," arguing that subsidies for green urban projects tend to privilege higher-income groups. Citizen-led organizations like Groen Good and Stadskwekerij de Kas, also aim to reduce systemic poverty, create nurseries, and increase biodiversity (Groen Good, 2019; Stadskwekerij De Kas, 2019).

Rotterdam currently has seven large-scale greening projects (Alexanderplein, Rijnhavenpark, Hofbogen, Maashavenpark, Hofplein & Westblaak, Schouwburgplein, and Tidalpark Feyenoord). These aim to increase urban green spaces to enable residents to have a park within a 15-min walk. The municipality states that in greening, emphasis will be paid to vegetation beneficial to humans and non-humans. Its Programme for Biodiversity plans to create healthy ecosystems, maintain urban green spaces, and make Rotterdam a nature-inclusive city by 2050 (Gemeente Rotterdam, 2022a,2023).

Current plans rely on citizen input, especially from local residents, yet there is a lack of data and information on whether issues of accessibility and justice are being considered. The Municipality only mentions that park construction might bring health benefits to low-income residents (Gemeente Rotterdam, 2022a) but does not give details. Areas in Rotterdam South, like the Afrikaanderplein, a neighbourhood close to Nelson Mandela Park, one of the seven big park projects, where around 83% of the population have an immigration background (AlleCijfers, 2023), are highlighted as areas of concern as population diversity in terms of migration background may not intersect with inclusive, accessible, and just urban green spaces (Haas, 2017; Stuiver et al., 2022). Greening Rotterdam is important for the Municipality (Gemeente Rotterdam, 2022a, 2022b) and citizens (Rotterdam Weerwoord, 2023), however, there is little information on how urban green projects impact residents demographically in Rotterdam South.

The municipality maintains and finances urban green spaces with an annual budget of €35.6 million (Rekenkamer, 2023). Owning 40% of the land, the municipality can implement its greening projects, but needs support from other stakeholders (Benders, 2016). The municipality aims at greening working locations, public spaces, nearby houses, and roofs (Gemeente Rotterdam, 2022b) through subsidies for smaller-scale initiatives and local businesses. This has enabled greening schools and school areas, greening businesses (Benders, 2016; Gemeente Rotterdam, 2022b; Mees and Driessen, 2011; Rotterdam Weerwoord, 2023), and 4600 m^2 of green roofs are being installed by private and public actors (Gemeente Rotterdam, 2022b). A climate adaptation subsidy scheme, started in 2020, aims to add 18,000 m^2 of green space (Gemeente Rotterdam, 2022b) and around 800,000 m^2 of green roofs by 2030 (Benders, 2016). For green roofs, the municipality depends on individual and collective initiative, although it aims to ensure that the process is transparent, respectful, inclusive, and legitimate (Benders, 2016).

Rotterdam increasingly maps social involvement and engagement levels on climate action by district. This enables identifying which districts need further help, and engaging citizens through access and information to greening subsidies and examples of initiatives (Rotterdam Weerwoord, 2023).

This means that it is critical to think about 'just' greening and explore how the BFI boundary and the overall ESJ framework resonate with the existing initiatives in Rotterdam. About 25% of the city is covered by green areas (i.e. 113 m^2 of green space per capita), but the spatial distribution across a 100 m^2 space lies at around 11% (HUGSI, 2022), meaning that urban green space is inequitably distributed across areas. There are no (in)direct policies regarding the BFI boundary, however, the Municipality aims to increase urban green spaces in "Rotterdam Gaat voor Groen" [Rotterdam Goes Green], successfully achieving the aim of 20 ha (200,000 m^2) of new urban green spaces by 2022 (Gemeente Rotterdam, 2022b). The municipality aims to add another 21.5 ha of green space (Rekenkamer, 2023).

4.3.2. Results of workshop discussions

On 22 January 2024, we organized a workshop with 12 experts from government, research, and civil society organizations to discuss justice and urban greening in Rotterdam. The discussion revolved around the large-scale Nelson Mandela Park to be built in the Maashaven in Rotterdam South, where 83% of the population has a migration background (AlleCijfers, 2023). The construction of this park and six other planned parks would likely achieve the 20-25% BFI boundary. The policies do not mention whether intragenerational, intergenerational and interspecies justice are being considered, although the Municipality mentions that the constructed park might bring health benefits to low-income residents (Gemeente Rotterdam, 2022a).

The workshop drew three conclusions. First, participants voiced concerns that urban green space projects in general had increased gentrification through increasing house prices, negatively affecting poorer people (I3). These intragenerational justice concerns are corroborated by earlier research (Kruize et al., 2007). However, recent increased access to urban green spaces in Rotterdam South have enhanced living standards for local residents (Haas, 2017). If this materializes for Nelson Mandela Park it would be an intragenerational justice success as the nearby Afrikaanderplein is a relatively marginalized area (Stuiver et al., 2022). However, such a park can increase real estate value risking gentrification. In addition, some participants felt that 25% may be inadequate to ensure the robust needs of the community. Responsible stewardship of biodiversity was necessary and implementing such a BFI requires assessing how possible it is given the pressure to construct housing.

Second, greening inadequately considers biodiversity and interspecies justice concerns (I1). While some attention has been paid to natural corridors and lighting there are also trade-offs with safety issues: streetlights can enhance safety but may disturb the nightlife of the park creatures.

Third, intergenerational justice concerns were also not considered (I2). While access and participation for current generations are a concern, future generations and thereby long-term planning were not a priority. Participants acknowledged that blindspot, however, and argued that inclusive participation in decision-making is critical to addressing wider social challenges, and partnerships between local actors and the municipality are essential to also address intragenerational issues.

Hence, none of the three I's are sufficiently considered in Rotterdam's urban green space planning even though the BFI may be met with current plans. Greening tends to be accompanied with high-priced real estate leading to gentrification. Biodiversity is taken into account but

there are trade-offs with housing and within parks with safety when it comes to lights. Future generations feature in broader green visions but not explicitly in the creation of current green spaces.

4.4. The African and Nigerian policy context

Moving to Africa, we see that the African Union (AU) aims at land conservation to protect its vast and diverse ecosystems threatened by deforestation, desertification, and climate change (Maze et al., 2005). During and post-colonization, laws focused on exploiting resources for export revenue, not conservation (Ogwu, 2023). Towards the end of the 1900s, African nations began to regulate to conserve wildlife and biodiversity. The Revised African Convention on Nature and Natural Resource Conservation (2003), in force since 2016, requires nations to protect biodiversity and conserve land (African Union, 2003). It has conservation objectives for land, soil, water, vegetation cover, and diverse species (African Union, 2003). Africa does not have a BFI boundary.

Three decades after Nigeria's independence from colonial rule, the government enacted the Nigerian Urban and Regional Planning Act (Decree 88, 1992), which outlined the roles of different government levels in planning and managing urban spaces (see Uzonnah et al., 2023). Since then, successive governments have enacted town planning regulations to promote UGS development by property developers and town planners. There is sparse literature and data on policies regarding urban green spaces (UGSs) under national policies and in Lagos metropolis. The Lagos State Development Plan (LSDP) 2022 – 2052 is the only comprehensive policy of the Lagos State Ministry of Economic Planning and Budget, and aims to harmonize and operationalize all high-level policy documents for the state (Ministry of Economic Planning and Budget, 2022). LSDP provides the strategy and direction for achieving the state's vision on economic and infrastructural development (including the provision of UGS), social services, protection and sustainable development. LSDP acknowledges that land-use and economic activities are unevenly distributed across the state with large swathes of open land in the eastern (Epe and Ibeju Lekki) and western (Badagry) areas of the city greatly affecting accessibility and inequality. The LSDP emphasizes that "limited availability and accessibility of UGSs present an opportunity for potential multifunctional green infrastructure (GI), which would improve environmental quality and the mental and psychological well-being of residents of the metropolis." It states that the highest proportion of UGS in Lagos metropolis are held by only two local government areas (LGAs) (Etiosa and Alimosho) in comparison with other LGAs (Ministry of Economic Planning and Budget, 2022).

4.5. The Lagos case

Lagos, Nigeria's capital, has 7390 people/km^2, with 26.5 million people today and expected to exceed 32 million by 2050. It is the 7th fastest growing city worldwide and covers 3577.2 sq. km. It consists of numerous townships and the European Quarters (or Government Reserved Areas, GRAs) which all developed autonomously. In 1902, development priorities led to converting the Lagos Botanical Station (2.4 ha) at Iddo into a Railway Terminal. In 1976, about 1176.22 acres were converted to recreational parks, with many falling within private commercial zones (e.g. Ikeja Country Club, Lagos Yacht Club, Yoruba Tennis Club, Nigerian Railway Club, Ikoyi Club 38, Obalende Polo Club, Lagos Island Club, Luna Amusement Park). Only about 2% of the green spaces were for leisure and recreational purposes (Adejumo, 2002). Thus, about 2.471 acres of urban green spaces were available for 40,000 people, falling very short of the global average, which is 2.471 acres per 600 residents. Since 2008, LASG has adopted urban greening via extensive tree-planting campaigns (Adeyemi and Shackleton, 2023; Fajemirokun, 2023).

4.5.1. The policy context

In the pre-colonial era, urban green spaces and UGI shaped Nigeria, when land was left to nature, and 60~80% of residential areas had green spaces. During colonization, Government Reserved Areas (GRAs) ensured that homes of colonial masters had a 60% green coverage. Following national policy in the 1990s, property developers and town planners started promoting urban green spaces. The Lagos State Development Plan (LSDP): 2022 – 2052 of the Lagos State Ministry of Economic Planning and Budget (2022) accepts that land use and economic activities are unevenly distributed with large swathes of open land in East (Epe and Ibeju Lekki) and West (Badagry) Lagos. It aims at potential multifunctional green infrastructure (GI) to enhance well-being and environmental quality.

The Lagos State Government's Climate Action Plan (CAP) 2020 – 2025 promotes a green and disaster-resilient Lagos. Goal 1 on climate adaptation seeks to strengthen urban ecosystem resilience, while Goal 2 aims at combatting flood risks. Between 2011 and 2020, 7.6 million additional trees were grown (Ayeni, 2021). Through creating awareness with international partners, the city aims to reclaim urban open spaces and promote an environmentally sustainable, healthier, and beautiful city while preserving biodiversity, mitigating climate impacts, and improving the quality of life. LASPARK develops, manages, and funds parks, gardens, and open spaces; grants permits for the use of open spaces; regulates the opening hours of parks; ensures security and sanitation services; promotes afforestation; and tags trees, including in private areas. From a spatial justice lens, Lagos lacks equitable distribution of urban green space and also excludes certain groups through entry fees to parks. About 95% of urban green space is in affluent neighbourhoods and locations formerly occupied by colonial rulers (Adegun, 2017).

4.5.2. Workshop results

The Lagos workshop on January 31, 2024 at the Lagos Chamber of Commerce and Industry (LCCI Conference & Exhibition Centre), Ikeja, involved 20 experts (from Lagos State Ministry of Environment and Water Resources, Lagos State Parks and Gardens Agency (LASPARK), Centre for 21st Century Issues (C21st), the International Climate Change Development Initiative (ICCDI), C40 Cities Climate Leadership Group, Urban Tree Revival Initiative (UTRI), Solution17 Innovation Hub, and academics).

Participants reported that property developers must reserve 50% of their plots for greenery (cf. Uzonnah et al., 2023). This goes beyond other policies (e.g., the Lagos State Urban and Regional Planning and Development Law (CAP U2) – Lagos State Physical Planning Permit Regulations, 2019) requiring that at least 10% of plots should be for greenery. At the same time, urban forests and other green spaces are being converted into industrial and residential areas, shrinking urban green space to $<$ 3 percent (cf. Oduwaye, 2013; Mensah, 2014). This contradiction results from competing and counterproductive policies and rules, misalignment of duties and responsibilities between agencies and NGOs, and increasing fragmentation to cope with the demands of a growing population.

In relation to the 3I's, participants felt that Lagos has not really considered the justice implications of urban green space and noted that (a) most urban green space (e.g. 327 urban parks and gardens of which 212 were established by the state government, 81 by private organizations and 31 by academic institutions): is in economically advantaged areas (I3). Intragenerational justice, gets squeezed as successive governments have neglected the needs of the poorest to green areas, and because 'slum' areas are seen as 'temporary'. To generate funds, participants proposed green taxes as a fine to those who default on their greening commitments (for indiscriminate tree felling, not planting trees, or carrying out soft landscaping); such money could both deter inappropriate behaviour and create resources for equitable sharing of urban green space. (b) I2, or intergenerational justice, is the most commonly applied, although development projects tend to lead to

environmental destruction (e.g. the 38 km-long 4th Mainland Bridge and the Lekki-Epe International Airport on 3500 ha of land). However, there is a massive tree-planting programme. I1, or interspecies justice, is integrated through accounting for biodiversity protection of native flora and fauna.

The Lagos case study reveals that despite a historical concern for greening, it now competes with development priorities. The state promotes tree planting and green requirements, but the bottom line is that most good quality greenery is in high-income areas. Green taxes could serve as a deterrent as well as a source of revenue for more equitable greening. Factors limiting the scaling-up of green justice in Lagos include counter-productive policies and the lack of priority for urban green space. Rapid urbanisation, lack of effective planning, lack of enforcement, and conflicting policies among local planners make the urban green target ineffective. While the government maintains that there are about 327 urban parks and gardens, many question the number, distribution, access, and quality of these spaces, and agreed that Lagos has many challenges in achieving, interspecies, intergenerational and intergenerational justice.

5. Analysis from a justice perspective

5.1. Applying earth system justice including the 3 I approach

Our policy analysis (see 4.1, 4.2, 4.4) reveals that the Earth Commission's biosphere intactness target of 50-60% of land is more stringent than global and European policy which is currently at 30% and this is not yet translated to the African, Netherlands and Nigerian context. The Earth Commission's BFI boundary is not found in any policy document, although the EU has a 3-30-300 voluntary rule which is less a boundary and more a rule of access for people. The global KM-GBF requires governments to include biodiversity in spatial planning, but does not explicitly account for interspecies, intergenerational and intragenerational justice. This implies first, that the workshop 1 critique that Earth System Justice did not adequately account for nature (see 2.2) is harsh given that its operationalization goes considerably further in protecting nature than current policy goals; and second that the proposed BFI boundary (and the intactness boundary) will be politically difficult to achieve.

Our case studies yield valuable insights. The Rotterdam case shows that living standards improve when a neighbourhood becomes greener (Haas, 2017). However, ensuring that poorer populations have equitable access (recognition justice) is challenging in Rotterdam and Lagos although the scale of the problem is different confirming the scholarship (Dzhambov et al., 2023; Mullenbach en Baker, 2020; Rigolon and Németh, 2018). Interspecies justice (I1) is not really discussed, but policymakers do talk about using appropriate and native species in Rotterdam and Lagos, but mostly from an anthropocentric perspective. Streetlights, for example, in Rotterdam are needed for safety but may disturb the lives of other species. There is little talk of I2 (intergenerational justice) in Rotterdam with neither past nor future playing a role. In Nigeria, the post-colonial structures have a shadow on present decisions with colonial houses and neighbourhoods retaining a much greener landscape. Future generations do not seem to get much attention except that development is prioritized over harm from de-greening. Intragenerational justice (I3) issues are probably the most discussed: in Rotterdam – making the city attractive to foreign migrants has gone against the interests of local people; low-income people have less access to green or access to poor quality green, even though there is a 25% canopy and 113 m^2 green space per capita. Moreover, Rotterdam is building parks to ensure that they are a 15 min walk away; it also gives subsidies for rooftop greening, which alas is acquired more by rich people. When the new park is completed, Rotterdam will have probably met the 20-25% BFI target; although the risk of gentrification looms large as greening is mostly allocated by the market. However, in Lagos there is less than 16.6 m^2 of greening per capita and this number will decrease as population grows. Green areas are unevenly distributed throughout the city. Although the city historically had open urban spaces, the need for jobs and development priorities has meant that there is less than 3% of open land and many parks are subject to fees making them inaccessible to the poor (I3). The risk of gentrification is very high with greening concentrated in rich areas; although builders are obliged to reserve 50% of the land for greening, this will probably serve the rich (I3) (Wolch et al., 2014; Cole et al., 2017; Anguelovski et al., 2022). Procedural justice is better developed in Rotterdam than in Lagos. There was inadequate information in both cities as to how such a BFI could be tailored to account for the specific contexts of each city, although on average it appeared that Rotterdam was on its way to meet the 20-25% BFI.

Fig. 2 modifies the operationalized ESJ framework through *ends* and *means* for the Biosphere functional integrity boundary. In applying this to ends, in terms of access, we refer to the EU 3-30-300 guideline. This complements the Earth Commission boundary. In terms of means, we argue that the root causes of de-greening and inequality (power and income distribution, historic processes, development pressures, market pressures) need to be addressed through revisiting spatial allocation mechanisms, liability for causing damage to nature (e.g. deforestation, not meeting greening commitments), and re-allocating responsibility. We explicitly incorporate power within the drivers of de-greening, and the risk of gentrification in the high-income countries and the added risk of development goals outcompeting environmental ones in low and middle-income countries.

5.2. Analysis of the justice criteria of the boundary

Section 2.2 discussed 9 criteria of relevance to just boundaries. Table 1 applies these in our study.

Our case studies reveal key insights that need testing in future research: (a) cities with a robust planning culture such as Rotterdam may be better able to promote a green policy landscape; while cities with a more fluid governance approach such as Lagos are less involved in green transition plans. (b) Colonized cities where greening was concentrated in areas where the 'colonialists' lived face the problem of path dependency post-independence; in contrast to cities that were not colonized may not have this history of extreme inequality in land ownership and 'greening'. (c) Cities that use the market to allocate land and greening such as Rotterdam and Lagos may inadvertently find that greening is focused in rich rather than poor areas. (d) City governments that own land (e.g. the municipality of Rotterdam owns 40% of the land). could themselves focus on greening their land and ensuring public access to these lands. (e) Richer cities may be able to prioritize greening and the health of their people; they may be able to subsidize greening efforts by people; however, richer people are better able to access these subsidies than poorer people – which exacerbates inequality. (f) Poorer cities may be focused on using their land to maximize economic returns; moreover, the rapid pace of urbanization and immigration implies that land is often scarce – this may decrease the land for greening; moreover they have to device green taxes to ensure that there are resources for greening a city. (g) Cities with high inequality may have privately owned parks or parks subject to entry fees making them inaccessible for poorer people. (h) Cities with an aware and active civic society and public have publics that demand 'inclusive greenery' – creating the enabling conditions for greening the city (e.g. Rotterdam); in contrast to cities where people are struggling for survival (e.g. Lagos). (i) The quality of greening is also important – with poorer neighbourhoods arguing that they are exposed to poor quality green while richer neighbourhoods may have high quality green. (j) Finally, richer cities like Rotterdam with a robust policy framework and active citizenry that together are implementing strategies such as organizing large parks and subsidizing small greening initiatives, suggest that they may be on the way to achieve the 3-30-300 and BFI boundary.

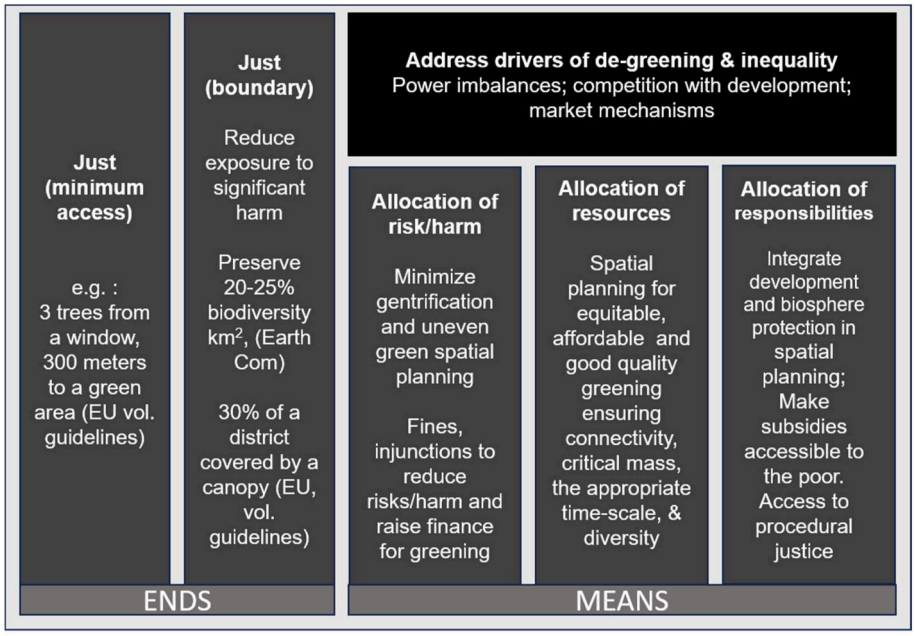


Fig. 2. Earth System Justice applied to Biosphere functional integrity boundary.

Table 1
Learning from case studies to enhance understanding of just boundary criteria.

Boundaries must:	Rotterdam	Lagos
Have a qualitative aspect	Account for the quality of greening; use appropriate and native species	Need to use native species
Account for context	Rich, stable Rotterdam has many greening plans; market based approach affects equitable access	Poorer, densely populated, urbanizing Lagos has historical inequities; parks with fees reduce access; market-based approach affects equitable access. BFI target competes with development priorities
Be translated locally	The BFI target of 20-25% of every kilometre appears feasible	The 20-25% target could be integrated into development policy
Be assessed spatially	Neither city has spatially mapped where the green-blue areas are in relation to the per square km rule. However, Rotterdam is more green at 113m^2 per capita) than Lagos with 16.6m^2 per capita	
Be linked to poverty analysis	Neither city has spatially mapped how green areas overlap with poverty; but both Lagos and Amsterdam have green areas concentrated in wealthy areas	
Be linked to who/ what causes problems	Both workshops revealed that market based approaches lead to more greening in rich areas, while the poor and elderly need these spaces most; such approaches are inappropriate for allocating green spaces	
Be achieved in a just manner	Avoid gentrification & expropriation; spatial planning on a per square km basis and using municipal lands; poor people need help to access subsidies	Green fines, could raise resources for greening, if levied on those who damage or do not fulfil greening obligations. Need to avoid gentrification
Be assessed in terms of what it can or cannot do	Such a boundary could potentially enhance the health and wellbeing of the poorest in Rotterdam	Such a boundary could enhance access to poorer people; but development challenges loom large
Be debated & adopted locally	Social movements for inclusive greening exist in Rotterdam	There are no real social movements for inclusive greening in Lagos
	Field work revealed that local discussion is essential for boundary contextualization and legitimacy; participants did not reject the idea of the BFI boundary	

6. Conclusion

In analysing the challenges and potential of adopting and implementing a safe and just biosphere integrity (BFI) boundary using Earth System Justice (ESJ) in urban policies in different contexts, we came to the following conclusions.

First, both the ecosystem literature and the urban literature find converging evidence that greening (e.g. a BFI boundary) can enhance ecosystem health and the health and wellbeing of people – especially the poor and elderly. However, the proposed BFI boundary is ahead of global, EU/African and national policy, although the EU's voluntary guideline which focuses on 3 trees from a window, 30% canopy and 300 m to a park can complement the boundary.

Second, in Rotterdam and Lagos, good quality green is inequitably distributed with the wealthier neighbourhoods having more access. When poorer neighbourhoods are 'greened', prices go up and residents get displaced. However, such a per km^2 BFI boundary could potentially 'green' *all* neighbourhoods and avoid the gentrification problem.

Third, the relatively wealthy and well-organized institutional framework of Rotterdam shows that it may well achieve this boundary even though the risk of gentrification, displacement and skewed distribution of subsidies for rooftop greening is ever-present. For Lagos, an urbanizing, densely populated city, development goals compete with greening goals. Our ten lessons (see 5.2) could serve as hypotheses for testing in other cities in high and middle income countries.

Fourth, the urban scholarship, green policies and the case studies have enabled us to enhance our application of Earth System Justice (see Fig. 2) as well as verify and improve our criteria for good boundaries (see Table 1).

Finally, we believe that if this BFI boundary is adopted contextually, it may enable a more equitable distribution of good quality and accessible green (if not subject to fees) especially for the people who need it most. Such boundaries are a key part of any Earth System Governance framework. They set the ambition level to achieve a socio-ecological goal. But clearly, as the criteria elaborate (see Table 1) they must be contextually relevant and scaled appropriately, locally debated and achieved justly.

CRediT authorship contribution statement

Joyeeta Gupta: Writing – review & editing, Writing – original draft, Project administration, Methodology, Funding acquisition, Conceptualization. **Agni Kalfagianni:** Writing – review & editing, Writing – original draft, Investigation. **Chukwumerije Okereke:** Writing – review & editing, Writing – original draft, Validation, Supervision, Investigation. **Fran Meissner:** Writing – review & editing, Writing – original draft, Validation. **Abhigyan Singh:** Writing – review & editing, Writing – original draft, Methodology. **Carissa Champlin:** Writing – review & editing, Writing – original draft, Methodology. **Alyssa Delarosa:** Writing – review & editing, Writing – original draft, Validation, Investigation. **Sofi Joaquín Fernández:** Writing – review & editing, Writing – original draft, Methodology, Investigation, Data curation. **Miguel Avides:** Writing – review & editing, Writing – original draft, Validation, Investigation, Data curation. **Zoé Sarolta Héjja:** Writing – review & editing, Writing – original draft, Formal analysis, Data curation. **Chukwueloka Okeke:** Writing – review & editing, Writing – original draft, Investigation, Formal analysis, Data curation, Conceptualization. **Elin Wahlqvist:** Writing – review & editing, Writing – original draft, Methodology, Investigation, Data curation, Conceptualization. **Paola Fezzigna:** Writing – review & editing, Writing – original draft, Conceptualization.

Declaration of competing interests

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Data availability

Interviews are anonymous under European Law. All other data mentioned is in the public domain.

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